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CHEMICAL ANALYSES AND PRELIMINARY INTERPRETATION OF WATERS COLLECTED FROM THE CGEH NO. 1 GEOTHERMAL WELL AT COSO, CALIFORNIA

By

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INTRODUCTION

The Coso Geothermal Area is located in east central California (figure 1) on land included in the U.S. Naval Weapons Center, China Lake.

Figure 1. Index Map showing the location of the Coso Geothermal Area.

Using funds provided by the U.S. Department of Energy, the Coso Geothermal Exploration Hole (CGEH) No. 1 was drilled approximately 1.9 km north of Devil's Kitchen and 3.2 km west of Coso Hot Springs. The well was completed in late November, 1977 at a total depth of 4,845 feet (1,477 m). Upon completion of drilling the static water level remained at -888 to -900 feet (-270 to -274 m). On December 2, 1977 the well was stimulated into production for approximately one hour by continuously pumping air to the bottom of the well. The rate of water production was 230 bbl/hr (36.6 m^3/hr) at the start and 184 bbl/hr (29.3 m^3/hr) at the end of the production period. During the flow test, water samples were collected at the wellhead every 15 minutes by Robert Galbraith of the University of Utah Research Institute. The waters were collected after separation of steam at atmospheric pressure withour prior conductive cooling. Unfortunately, the waters contained residual drilling mud to an extent that field filtration was impossible because of the almost immediate clogging of filters. Therefore, the usual acidified (for Ca and trace element analyses) and diluted (for dissolved silica analyses) samples were not prepared.

In the laboratory the mud was allowed to settle to the bottom of the sample bottles for two days, and then the clear liquid was decanted into another container through Whatman No. 41 ashless filter paper. The decanted liquids then remained quiescent for two weeks before the chemical analyses were initiated.

METHODS OF CHEMICAL ANALYSES

Sodium, potassium, rubidium, and *cesium* were determined by flame emission spectrophotometry using lithium as an ionization suppressant in the flame.

Lithium was determined by flame emission spectrophotometry using sodium as an ionization suppressant.

Strontium was determined by flame emission spectrophotometry after adding lanthanum and potassium to adjust the level of total ionization in the flame as described by Brown and others (1970) for atomic absorption.

Calcium and *magnesium* were determined by atomic absorption spectrophotometry using lanthanum, prepared as described by Brown and others (1970), to prevent interference by silica.

Total silica in the water was determined by atomic absorption using a nitrous oxide flame. Dissolved silica in the form of non-cyclic polymers was determined colorimetrically by the molybdenum blue method using a modification of the Shapiro and Brannock (1956) procedure (Rowe and others, 1973).

Bicarbonate and *carbonate* were determined by automatic titration using standardized sulfuric acid (~0.05 N) and a pH electrode.

Chloride was determined by automatic tritation using standardized silver nitrate (0.0147 N), a silver/silver chloride indicating electrode, and a double junction reference electrode.

Boron was determined by the carmin method (Brown and others, 1970).

Fluoride was determined by a fluoride specific electrode after adjusting the total ionic strength of the solution as described by Thompson and others (1975).

RESULTS AND INTERPRETATION

Chemical analyses of waters collected from the CGEH well No. 1 are shown in table 1, samples 2, 3, 4, 5, and 6. Also shown are chemical analyses of three waters (samples 7, 8, and 9) from a well drilled to 375 m at Coso Hot Springs (32. km E of CGEH No. 1) by the U.S. Navy in 1967 (Austin and Pringle, 1970). The waters from both wells are all rich in chloride, implying a hot-water system rather than a vapor-dominated system.

Table 1. Chemical analyses of waters from wells at Coso, California

Source of Sample	Makeup Water[1]	1977 CGEH Well No. 1[2]					1967 Coso Well No. 1[3]		
Sample Number	1	2	3	4	5	6	7[4]	8[5]	9[6]
Date of Collection		2 Dec. 77	2 Dec. 77	2 Dec. 77	2 Dec. 77	2 Dec. 77	27 Jun. 67	Mar. 68	Mar. 68
Time of Collection		10:45 A.M.	11:00 A.M.	11:15 A.M.	11:30 A.M.	11:45 A.M.			
Sample temp. in well °C		~165	~165	~165	~165	~165	116	142	142
Constituent, ppm									
SiO_2	63	710[7]	710[7]	710[7]	710[7]	710[7]	50	27	154
Rb	<.02	.103	.105	.106	.112	.118			
Cs	<.01	<.01	<.01	<.01	<.01				
Ca	100.	110.	98.	99.	93.	98.	72.8	359	74.4
Mg	29.8	3.0	2.5	2.3	2.7	2.5	0.5	0.6	1.0
Sr	0.8	3.9	3.8	3.8	3.7	3.7			
Na	100	1600	1600	1580	1590	1590	1764	2808	1632
K	0.5	122.	123.	125.	126.	126.	154.	172.	244.
Li	1.0	9.6	9.7	10.	10.3	10.			
HCO_3	307.	150.	286.	273.	297.	279.	134.2	0.0	0.0
CO_3							84.	50.4	77.4
SO_4	234.	314.	268.	266.	257.	245.	38.	216.	52.8
Cl	81	2330	2360	2420	2460	2480	2790	3681	3042
F	<0.1	3.8	3.8	3.8	3.8	4.2	3.7	1.6	2.2
B	.92	54.	53.	54.	56.	58.	48.	57.4	71.6
C.T.D.S.	918	5410	5518	5547	5610	5606	5744	6894	5228
Cations	11.98	79.83	79.24	78.50	78.72	78.92			
Anions	12.18	74.92	77.04	78.47	79.81	79.84			
pH	7.67	8.14	7.74	8.15	8.14	8.22	8.9	9.8	8.5
B/Cl, atomic proportion	.037	.076	.074	.073	.075	.077	.056	.051	.077
K/Cl, atomic proportion	.006	.047	.047	.047	.046	.046	.050	.042	.073
Na-K-Ca T, °C		191	192	194	195	195	205	179	238
Analytical Lab	USGS[9]	USGS[9]	USGS[9]	USGS[9]	USGS[9]	USGS[9]	Navy	Hornkohl	Hornkohl

[1] Makeup water for the drilling mud used in the CGEH Well No. 1.

[2] Collected by Robert Galbraith of the University of Utah Research Institute. Samples collected at the wellhead after separation of steam at atmospheric pressure.

[3] Well drilled to a depth of 375 feet (114.3 m) at Coso Hot Springs by the U.S. Navy, Coso Naval Weapons Center. Well data and chemical analyses reported by C. F. Austin and J. K. Pringle (1970). Samples 7, 8, and 9 correspond to samples 1, 2, and 3 in Table 12 of Austin and Pringle (1970).

[4] Sample taken from the well discharge (clear water) at completion of drilling after blowing the well with compressed air for over one hour.

[5] Sample is from the first and third bailer, taken after the well was idle for 7 months.

[6] Sample is from the 13th and 14th bailer, taken after the well was idle for 7 months.

[7] The silica value includes possible silica from colloidal clay dispersed in the water and therefore, may not be indicative of the actual dissolved silica in the water.

[8] This HCO_3 value probably is in error. There were too few anions found to balance the cations. Judging by the general agreement of all other constituents in sample 2 with samples 3 through 6, the HCO_3 value for sample 2 should be close to 280 ppm.

[9] J. M. Thompson, analyst.

During drilling there were repeated and persistent problems with lost circulation in the CGEH No. 1 well. Over 350,000 gal (~1,300,000 liters) of makeup water and over 291,000 lb (~132,000 kg) dry weight of mud were injected into the formation. Because samples 2 through 6 were collected soon after drilling was terminated and before a large amount of fluid was produced, it is not now known to what extent, if any, these samples are mixtures of formation water and makeup water (sample 1, table 1). Chemical and isotopic analyses of water samples collected from the well in the future should answer this question.

A plot of boron relative to chloride is shown in figure 2. The B/Cl ratios in the CGEH well No. 1 samples, numbers 2 through 6, are very similar to the B/Cl ratio in sample 9 from the shallow well drilled in 1967 at Coso Springs, and distinctly different from the ratios in samples 7 and 8, also from the Coso Springs well (table 1 and figure 2). The CGEH waters could be mixtures of water similar to sample 9 and either makeup water or other dilute water that entered the system naturally. Sample 7 probably is a mixture of makeup water used in 1967 and sample 8 water with a small component of sample 9 water because the sample 7 type of water was only found immediately after drilling was terminated. The relationship of the sample 8 and 9 waters is uncertain. It is possible that sample 9 water was transformed to sample 8 water by boiling with chloride concentrated in the residual liquid and appreciable boron fractionated into the separated steam phase.

Figure 3 shows a plot of potassium relative to chloride for the waters tabulated in table 1. Again samples 8 and 9, from the shallow Coso Springs well, are distinctly different. The K/Cl ratio is not likely to have changed just as a result of steam separation. If samples 8 and 9 are related by boiling, there must have been water-rock reactions after the boiling to further change the water composition of sample 8. Variations in other dissolved constituents also suggest that water-rock reactions have played an important role in determining the different compositions in samples 8 and 9. Application of the Na-K-Ca geothermometer (Fournier and Truesdell, 1973) suggests that the sample 9 water equilibrated at 235°C and that sample 8 water equilibrated at 179°C.

In contrast to the results shown in the plot of boron relative to chloride (figure 2), in the plot of potassium relative to chloride (figure 3) the samples from the CGEH well No. 1 do not lie along a mixing trend between sample 9 and dilute water (possibly makeup water). This suggests that the waters produced from the CGEH well have undergone water-rock re-equilibration after mixing. The Na-K-Ca geothermometer gives 191° to 195°C for the temperature of last chemical equilibration.

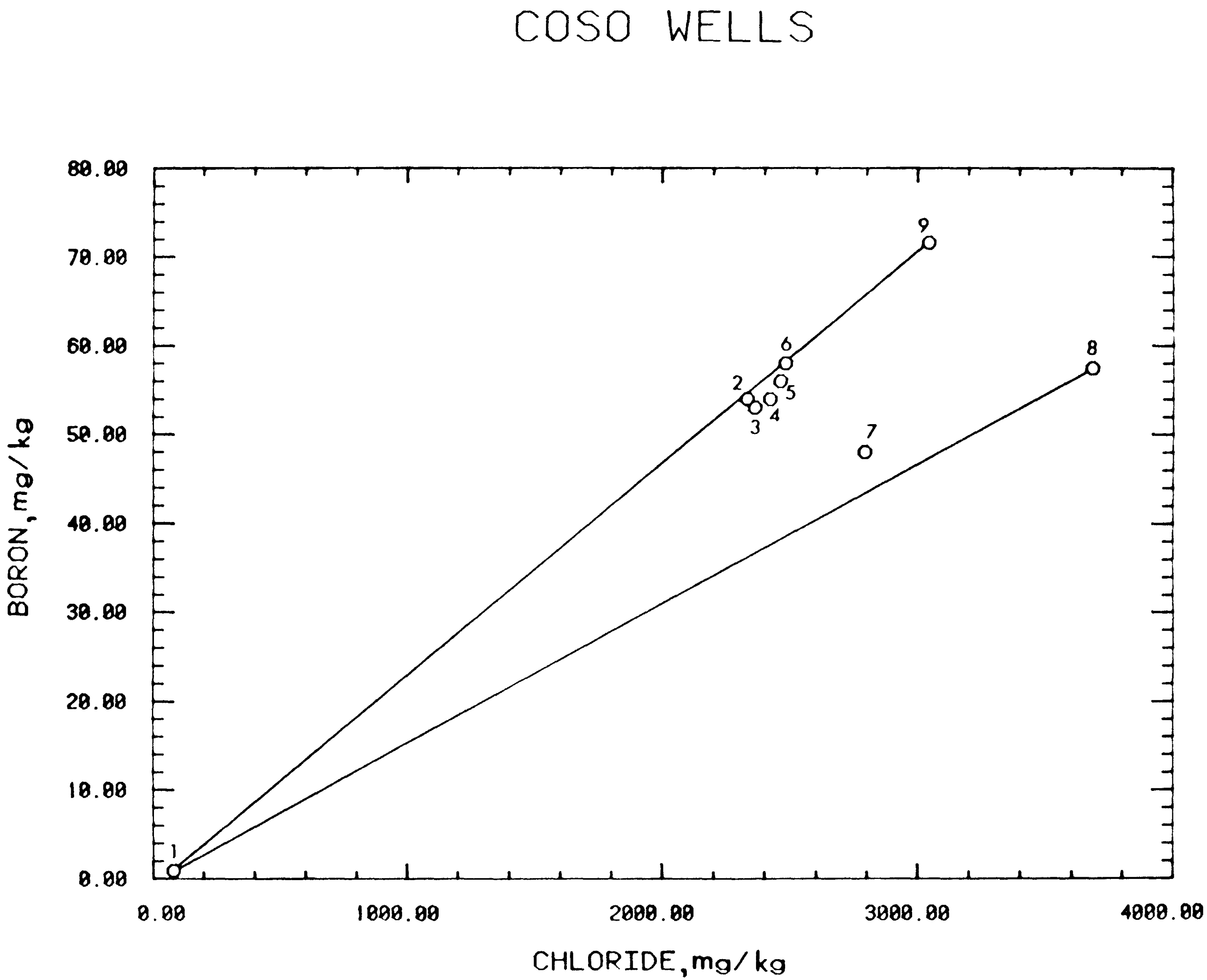

Figure 2. Plot of boron relative to chloride for the well waters tabulated in Table 1.

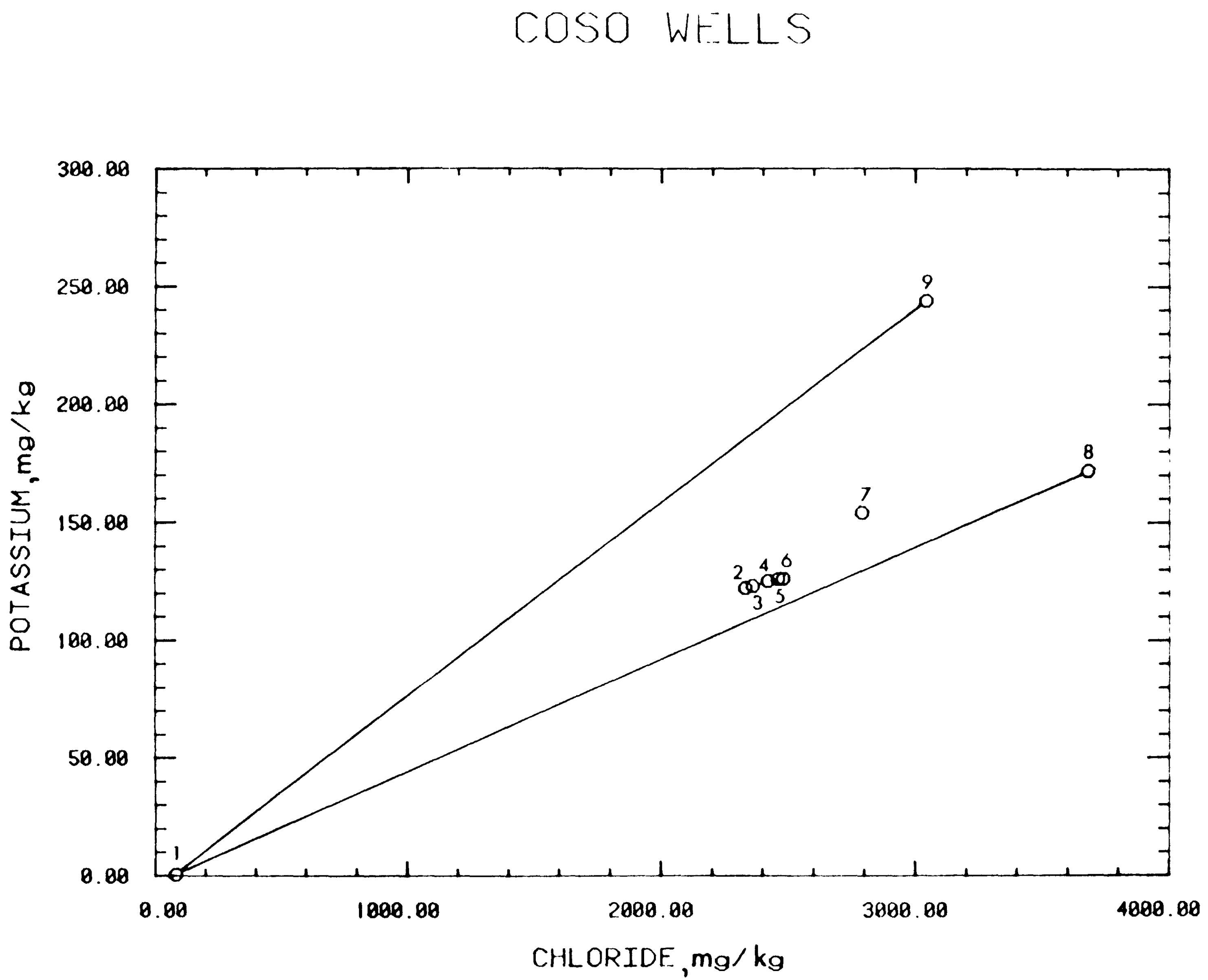

Figure 3. Plot of potassium relative to chloride for the well waters tabulated in Table 1.

Plots of enthalpy relative to chloride are useful for showing the extent of boiling and mixing processes in geothermal systems (Fournier, White and Truesdell, 1976; Truesdell and Fournier, 1976). The construction and use of this type of diagram are discussed in detail by Fournier (in press). Figure 4 is an enthalpy-chloride plot for well waters from Coso. In figure 4, lines radial to the enthalpy and chloride content of steam* show trends of enthalpy and chloride in the residual liquid phase after varying amounts of steam separation; lines radial to dilute, non-thermal water, such as N, show results of mixing of that non-thermal water with thermal waters. Except for point S (steam) the plotted points show enthalpies of liquid water in thermal equilibrium with steam. These enthalpies were obtained using steam tables and either measured or Na-K-Ca geothermometer temperatures of the various indicated waters, assuming that the small amounts of dissolved salts caused negligible departure from the pure water system. The numbered triangles correspond to numbered samples in table 1; they are plotted at the measured conditions of the samples at the time of collection at the wellhead. The large dots labeled A through F show estimated conditions at depth prior to steam separation; their temperatures were estimated using the Na-K-Ca geothermometer. Temperatures corresponding to points G, H, J, and K in figure 4, are maximum measured temperatures in the wells close to the time of sampling. The placement of points A and B in figure 4 was done assuming (1) conductive cooling of the water from 195°C (the Na-K-Ca temperature) to 165°C (the approximate maximum temperature in the well at the time of sampling); (2) maximum steam separation during decompression from 7 x 10^5Pa at 165°C to atmospheric pressure at 97°C; and (3) water-rock chemical equilibrium at 195°C (re-equilibrated at 195°C after mixing?). According to measurements made by personnel of the Lawrence Berkeley Laboratory, since termination of drilling the maximum temperature in the CGEH No. 1 well has been slowly increasing (~190°C on February 10, 1978) and the probable upper limit is about 195°C (R. Schroeder, written communication, 1978), the temperature indicated by the earlier Na-K-Ca data.

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* The enthalpy of steam ranges from 2,676 to 2,804 joules per gram in the temperature range 100° to 300°C with a maximum enthalpy at 235°C. As a simplifying assumption a constant value of 2,775 joules per gram (178°C steam) was used for point S in figure 4 and straight line boiling trends were drawn radial to S. For very precise work, the changing enthalpy of steam should be taken into account so that the boiling trends are slightly curved lines in the temperature range 100° to 300°C. However, neglecting this curvature introduces no more than 2° or 3°C error in the estimated temperatures of the various plotted points.

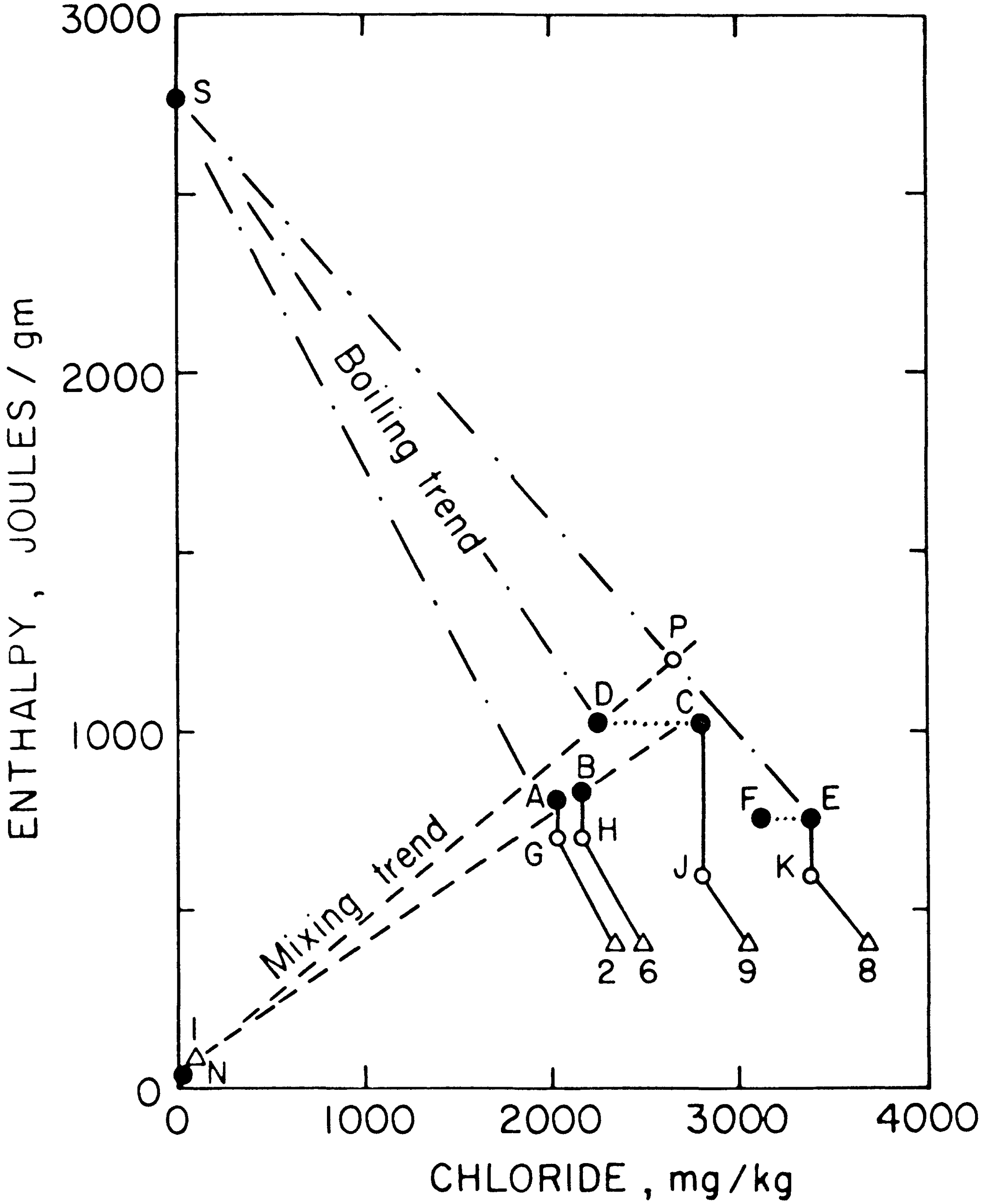

Figure 4. Plot of enthalpy of liquid water relative to chloride for representative well waters tabulated in Table 1. See text for discussion.

Apparently waters 8 and 9 entered the shallow 1967 Coso Hot Springs well No. 1 from hotter regions at depth. For sample 9, point J gives the condition of the water at the bottom of the well. Although the water boiled in the bailer during sampling, it is not known whether sample 9 water boiled and lost steam before entering the well (decompressional cooling, extension of the boiling line through D and J to 9, or whether that water cooled entirely by conduction before entering the well (line CJ). A combination of boiling and conductive cooling during ascent could have occurred so that the original condition of the deep water could have been anywhere along line CD. Similarly, the condition of sample 8 water may have been anywhere along line EF, depending on the relative amounts of conductive and decompressional cooling.

If all the well waters at Coso are related to a deep, high-temperature, chloride-rich parent water that is modified by boiling, by mixing with dilute, non-thermal water, and by water-rock re-equilibration at lower temperature, then the minimum enthalpy and corresponding chloride of that parent water should lie at the intersection of the uppermost boiling and mixing trend lines. In figure 4, depending on the relative amounts of conductive and adiabatic cooling of waters 8 and 9, that intersection could range from point C, with a temperature of about 240°C, to point P, with a temperature of about 275°C.

CONCLUSIONS

The chloride-rich water obtained in 1967 from the shallow (114.3 m) Coso Hot Springs well No. 1 comes from a deep aquifer with a temperature at least as high as about 240° and possibly higher than 275°C. Similar, but slightly diluted and cooled chloride-rich water enters the 1477-meter deep CGEH No. 1 well drilled in 1977 about 3.2 km to the west of the 1967 well. From the data in hand the Coso geothermal system appears to be a hot water type. The surface expression of fumarole and acid sulfate pools and shallow steam wells gives a false indication of an extensive vapor dominated system because upward convecting, boiling alkaline-chloride waters do not reach the surface.

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